EFFECT OF DOUBLE STRATIFICATION ON BOUNDARY LAYER FLOW AND HEAT TRANSFER OF NANOFLUID OVER A VERTICAL PLATE IN THE PRESENCE OF CHEMICAL REACTION

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This work is dedicated to my beloved parents

Rahamat bin Abd Jabar and Asmah binti Pukari

For their endless love, support, encouragement and blessing

I am honoured to have you as my parents

A special thanks to my loving husband

Md Ebrahim bin Tukiyat

Who has been a great source of motivation and inspiration

For the deep support, undying love, trust and encouragement continues to surround and support when this task looked like more than I could handle

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ABSTRAK

Masalah stratifikasi berganda ke atas aliran lapisan sempadan dan pemindahan haba teraruh kerana cecair nano di atas plat menegak dengn kehadiran tindak balas kimia disiasat. Nanopartikel mempunyai potensi yang besar untuk meningkatkan sifat-sifat pengangkutan haba berbanding dengan zarah konvensional cecair penggantungan, meter mili dan zarah bersaiz mikro meter. Persamaan pengangkutan yang digunakan dalam analisis termasuk kesan gerakan Brownian, parameter thermophoresis, nisbah parameter keapungan, parameter stratifikasi haba, parameter stratifikasi solutal dan parameter kadar tindak balas kimia. Persamaan pembezaan biasa bukan linear dan syarat sempadan yang berkaitan mereka pada mulanya diturunkan ke bentuk berdimensi oleh pembolehubah persamaan. Sistem yang mengakibatkan persamaan ini kemudiannya diselesaikan secara berangka dengan menggunakan perisian komputer algebra MAPLE 18. Perisian ini menggunakan perintah keempat kelima kaedah Runge Kutta Fehlberg sebagai kaedah untuk menyelesaikan masalah nilai sempadan secara berangka menggunakan arahan dsolve itu. Keputusan berangka yang diperolehi adalah halaju berdimensi, suhu berdimensi dan taburan kepekatan zarah berdimensi. Hasil daripada analisis didapati bahawa halaju berdimensi bendalir berkurangan dengan kenaikan parameter startifikasi haba dan stratifikasi solutal. Keputusan berangka dibandingkan dan didapati bersetuju dengan keputusan yang diterbitkan sebelum ini pada kes-kes khas daripada masalah yang dikaji.

ABSTRACT

The problem of double stratification on boundary layer flow and heat transfer induced due to a nanofluid over a vertical plate in the presence of chemical reaction is investigated. Nanoparticles have a great potential to improve the thermal transport properties compared to conventional particles fluids suspensions, mili meter and micro meter sized particles. The transport equation which employed in the analysis including the effect of Brownian motion, thermophoresis parameter, buoyancy ratio parameter, thermal stratification parameter, solutal stratification parameter and chemical reaction rate parameter. The non-linear governing equations and their associated boundary conditions are initially cast into dimensionless forms by similarity variables. The resulting systems of equations are then solved numerically by using very robust computer algebra software MAPLE 18. This software uses a fourth-fifth order Runge Kutta Fehlberg method as a default to solve boundary values problems numerically using the dsolve command. Numerical results are obtained for dimensionless velocity, temperature and concentration distribution of particles. It is examined that the dimensionless velocity of the fluid decreases with the increases of thermal and solutal stratification parameter. The numerical results are compared and found to be in good agreement with the previous published result on special cases of the problem.

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LIST OF SYMBOLS

NOMENCLATURE

A	the cross-sectional area to flow
C_f	skin friction coefficient
$C_{\infty;0}$	ambient concentration
D_B	Brownian diffusion coefficient
D_T	thermophoresis diffusion coefficient
f	dimensionless stream function
h	dimensionless concentration function
k	thermal conductivity
κ	the intrinsic permeability of the medium
Le	Lewis number
Nb	Brownian motion parameter
Nr	buoyancy ratio parameter
Nt	thermophoresis parameter
Nu_x	local Nusselt number
Pr	Prandtl number
(Pb - Pa)	the total pressure drop
q	the flux

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Ra_x	local Rayleigh number
Re	local Reynolds number
Sh_x	local Sherwood number
T	temperature of the fluid inside the boundary layer
$T_{\infty;0}$	ambient temperature
u, v	velocity component along x- and y-direction component along x- and y- direction

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GREEK LETTERS

α	Thermal diffusivity
β	Volume expansion coefficient
η	Dimensionless similarity variable
μ	Dynamic viscosity of the fluid
υ	Kinematic viscosity of the fluid
ε_1	Thermal stratification
ε_2	Solutal stratification
$(\rho)_f$	Density of the fluid
$(\rho C)_f$	Heat capacity of the fluid
$(\rho C)_p$	Effective heat capacity of a nanoparticle
Ψ	Stream function
Φ_w	Nanoparticle volume fraction at the surface
Φ_∞	Nanoparticle volume fraction at large values of y
θ	Dimensionless temperature
τ	$\frac{(\rho C)_p}{(\rho C)_f}$
Ɣ	Chemical reaction rate
f'	Dimensionless velocity
Φ	Dimensionless particle concentration

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CHAPTER 1

1.1 BACKGROUND

Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current; this process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density. Natural convection has attracted a great deal of attention from researchers because of its presence both in nature and engineering applications and also their various engineering and industrial applications in heat transfer process.. In nature, convection cells formed from air rising above sunlight-warmed land or water are a major feature of all weather systems. Heat transfer by natural convection frequently occurs in many physical problems and engineering application such as geothermal systems, heat exchangers, chemical catalytic reactors, fiber and granular insulation, packed bed, petroleum reservoirs and nuclear waste repositories (Wubshet Ibrahim, 2013 and O.D.Makinde, 2013). Moreover, natural convection of heat and mass transfer occurs in many areas such as in the field of designing chemical processing equipment, distribution of temperature and moisture over agricultural fields and formation and dispersion of fog. In this system heat is transferred from a vertical plate to a fluid moving parallel to it by natural convection. This will occur in any system wherein the density of the moving fluid varies with position. These

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phenomena will only be of significance when the moving fluid is minimally affected by forced convection.

Stratification of fluid arises due to temperature variations, concentration differences, or the presence of different fluids. In practical situations where the heat and mass transfer mechanisms run parallel, it is interesting to analyze the effect of double stratification (stratification of medium with respect to thermal and concentration fields) on the convective transport in micro polar fluid. The analysis of free convection in a doubly stratified medium is a fundamentally interesting and important problem because of its broad range of engineering applications. These applications include heat rejection into the environment such as lakes, rivers, and seas; thermal energy storage systems such as solar ponds; and heat transfer from thermal sources such as the condensers of power plants. The effect of stratification is an important aspect in heat and mass transfer and has been studied by several researches. In real-world situations where heat and mass transfer run simultaneously, it is significant to investigate the effect of double stratification on the convective transport by using nanofluid. A stratified fluid consisting of fluid parcels of various densities will tend under gravity to arrange itself so that the higher densities are found below lower densities. The vertical layering introduces an obvious gradient of properties in the vertical direction, which affects the velocity. Stratified fluids are universal in nature, present in almost any heterogeneous fluid body such that heterogeneous mixture in industries, salinity stratification in estuaries, density stratification of the atmosphere and many more example.

Analysis of thermal stratification is very important for solar engineering because higher energy efficiency can be achieved with better stratification and already shown by researchers that the thermal stratification in energy storage may significantly increase system performance. Chen and Eichorn, 1998, have been analyzed that natural convective flow over a heated vertical surface in a thermal stratified medium using the local non similarity method for the solution of the governing equations. The study is concerned with a natural convective flow of common fluids by the effects of double stratification on boundary layer flow and heat transfer of nanofluid over a vertical plate in the presence of chemical reaction because nowadays the natural convective flow and heat transfer using nanoparticle suspension in a base fluid has been active research area. The nanofluid is an advanced type of fluid containing nanometer sized particles (diameter less than

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100nm) or fiber suspended in the ordinary fluid. Definitely the nanofluid are beneficial in the sense that the area more stable and have an acceptable viscosity and better wetting, spreading and dispersion properties on a solid surface. Nano fluids are used in different engineering application such as microfluidics, microelectronic, transportation, biomedical, solid state lighting and manufacturing. The research on heat transfer in nanofluid has been receiving increased attention worldwide.

Studies have been shown that a nanoparticle suspension in a base fluid curiously changes the transport property and heat transfer characteristic of a convectional base fluid. A uniform suspension of nanometer size solid particles and fiber in convectional base fluid is called nanofluid. Nano material is a new energy material since its particle size is the same as or smaller than the wavelength of de Broglie wave and coherent wave. Therefore, nanoparticle becomes too strongly absorb and selectively absorbs incident radiation. Based on the radiative motion properties of nanoparticle, the utilization of nanofluid in solar system becomes the new study hotspot. Scientist and engineers today are seeking to utilize solar radiation directly by converting it into useful heat or electricity.

Chemical reaction effects on heat and mass transfer are of considerable important in hydrometallurgical industries and chemical technology. In many chemical engineering processes, a chemical reaction occurs between a foreign mass and the fluid. A chemical reaction can be described as either a heterogeneous or homogeneous process, which depend on whether it occurs at an interface or as a single-phase volume reaction. Furthermore, research on combined heat and mass transfer with chemical reaction and thermophoresis effect can help in food processing, cooling towers, chemically reactive vapor deposition boundary layer in optical materials processing, catalytic combustion boundary layers, chemical diffusion in disk electrode modeling and carbon monoxide reactions in metallurgical mass transfer and kinetics. Several investigations have examined the effects of chemical reaction on the flow and heat and mass transfer past a vertical plate.

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1.2 PROBLEM STATEMENTS

In this project, we will study numerically as well as physically the effect of double stratification on boundary layer flow and heat transfer of nanofluid over a vertical plate in the presence of chemical reaction. The effects of various governing parameters such as thermal stratification ε_1, solutal stratification ε_2, Brownian motion parameter N_b, thermophoresis parameter N_t, buoyancy ratio parameter N_r and chemical reaction γ on velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles will be examined. The coupled of ordinary differential equations for different values of governing parameters which are obtained by applying the fourth-fifth order Runge-Kutta Fehlberg method then will be solved numerically by using MAPLE software. Then the obtained result is compared to the previous result that has been done.

1.3 OBJECTIVES OF STUDY

The objectives of this thesis are:-

1. To analyze the effect of various governing parameters such as thermal stratification ε_1, solutal stratification ε_2, Brownian motion parameter N_b, thermophoresis parameter N_t, buoyancy ratio parameter N_r and chemical reaction γ on dimensionless velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles.

2. To compare the numerical result on special cases of the problem with previous published result.

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1.4 SCOPE OF STUDY

This study is limited to the problem of effect of double stratification on boundary layer flow and heat transfer of nanofluid over a vertical plate in the presence of chemical reaction under some prescribed parameters effects. Some prescribed parameters, such as thermal stratification ε_1, solutal stratification ε_2, Brownian motion parameter N_b, thermophoresis parameter N_t, buoyancy ratio parameter N_r and chemical reaction γ on velocity$f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles.

The transport equations employed in this analysis which is including the effect of Brownian motion, thermophoresis, thermal stratification and solutal stratification; also the non-linear governing equations and their associated boundary conditions are initially cast into dimensionless forms by similarity variables. The set of equation are highly nonlinear coupled equations and cannot be solved analytically and numerical solution subject to the boundary condition. The set of equations are then obtained numerically by using the very robust computer algebra software Maple 18. This software uses a fourth –fifth order Runge Kutta Fehlberg method as default to solve boundary value problems numerically using the dsolve command.

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1.5 ORGANIZATION OF THE THESIS

Chapter 1 provides some briefing on analysis background, its application in real world, some problem statement, objectives of the analysis, and scope of the study. Chapters 2 present a literature review about the nanoparticle, nanofluid, thermal stratification, solutal stratification, double stratification, Rayleigh number, Reynolds number, what is chemical reaction either distractive or generative reaction,

Chapter 3 presents the method that will be used along the analysis, how to reduces the governing equation to the dimensionless form, some surface introduction of calculation, some introduction of MAPLE 18 command. It also shows the equation that will use with MAPLE 18.

Chapter 4 presents the result and discussion on what finding that been obtain from the simulation, how the prescribe parameters effect on velocity, temperature and concentration profile. Chapter 5 presents the conclusion on the objectives that has been achieved. Some of recommendations for future work also mentioned in this chapter.

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CHAPTER 2

LITERATURE REVIEW

2.0 NANOPARTICLE

Nanoparticles are particles between 1 and 100 nanometers in size. In nanotechnology, a particle is defined as a small object that behaves as a whole unit with respect to its transport and properties. Particles are further classified according to diameter. Ultrafine particles are the same as nanoparticles and between 1 and 100 nanometers in size. Coarse particles cover a range between 2,500 and 10,000 nanometers. Fine particles are sized between 100 and 2,500 nanometers. Nanoparticle research is currently an area of extreme scientific interest due to a wide variety of potential applications in biomedical, optical and electronic fields. Nanoparticles are of great scientific interest as they are, in effect, a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at the nano-scale size-dependent properties are often observed. Thus, the properties of materials change as their size approaches the nanoscale and as the percentage of atoms at the surface of a material becomes significant. For bulk materials larger than one micrometer (or micron), the percentage of atoms at the surface is insignificant in relation to the number of atoms in the bulk of the material.

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